The Perception Modification Concept to Free the Path of An Automated Vehicle Remotely

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Abstract: Inner-city, automated vehicles will face situations in which they leave their operational design domain. That event may lead to an undesired vehicle standstill. Consequently, the vehicle's independent continuation to its desired destination is not feasible. The undesired vehicle standstill can be caused by uncertainties in object detection, by environmental circumstances like weather, by infrastructural changes or by complex scenarios in general. Teleoperation is one approach to support the vehicle in such situations. However, it may not be clear which teleoperation concept is appropriate. In this paper, a teleoperation concept and its implementation to free the path of an automated vehicle is presented. The situation to be resolved is that a detection hinders the automated vehicle to proceed. However, the detection is either a false positive or it is an indeterminate object which can be ignored. The teleoperator corrects the object list and the occupancy grid map. Thereby, the teleoperator enables the automated vehicle to continue its path. The preliminary tests show that the teleoperation concept enables teleoperators to resolve the respective scenarios appropriately.

1 INTRODUCTION

The SAE J3016 (J3016, 2018) subdivides the automation of vehicles into six different levels of driving automation. The levels range from level 5 'Full Driving Automation' to level 0 'No Driving Automation'. In level 5 automation, no driver has to be present neither for supervision or as a fallback system. Furthermore, the automation system is not limited to an operational design domain. In contrast to level 5, level 4 systems are limited to a specific operational design domain which can be classified as environmental, geographical, or time-of-day restricted (J3016, 2018) among others. Therefore, level 4 systems are expected to be launched prior to level 5 systems. Whenever the automation system leaves its operational design domain, it has to come to a safe state. A safe state means a standstill for inner-city vehicles in many cases. As a consequence, passengers would be stranded. This should be avoided. Therefore, the motivation is to enable the automated vehicle (AV) to continue driving.

Teleoperation is a possible solution. The vehicle will request help from the control center via the mobile network (Feiler et al., 2020). A teleoperator connects to the vehicle and resolves the problem. This technology comes with several challenges.

First, the teleoperator has to be aware of the situation, that led to the help request. Camera streams and further vehicle sensor information are visualized to the teleoperator. Progress was made in improving video streaming (Gnatzig et al., 2013; Liu et al., 2016; Kang et al., 2018; Tang et al., 2013) and in increasing teleoperator immersion (Bout et al., 2017; Georg und Diermeyer, 2019; Tang Chen, 2014; Hosseini, 2018).

Second, the teleoperator has to resolve the situation reliably and safely. Different methods of interacting with the vehicle are possible. This spectrum ranges from low-level control commands to high-level teleoperation concepts. A low-level control concept is the direct control, where the teleoperator sets the desired velocity, the desired steering wheel angle and the desired gear. Direct control was implemented several times in the research context (Gnatzig et al., 2013; Liu et al., 2016; Ross et al., 2008). Progress was made in analyzing and reducing system latency (Ross et al., 2008; Blissing et al., 2016; Georg et al., 2020) and in designing teleoperation assistance systems (Hosseini, 2018; Chucholowski, 2015). However, the teleoperators are imposed by a high workload (Georg et al., 2018; Liu et al., 2016). As soon as a teleoperator steers a vehicle with low-level control commands, the teleoperator is responsible for avoiding accidents during the

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vehicle's motion. Due to the control from a remote location and system latency, the teleoperator can be overwhelmed by the imposed mental workload. Therefore, the motivation is to decrease the teleoperator's mental workload. In general, there are two approaches to reduce the teleoperator's mental workload: (1) Improvement of data representation (better videos and visualizations, head-mounted display, sensory feedback) and (2) Simplification of control tasks. Because several improvements regarding (1) have already been made, this article addresses simplification of control.

Summarizing the previous paragraphs, the motivation is that an AV is stranded and that possible teleoperation solutions place a high workload on teleoperators. The objective of this paper is to develop a teleoperation concept that enables the AV to proceed and that places a lower workload on teleoperators than direct control. Section 2 gives an overview of high-level teleoperation concepts, their application and related architectural considerations. Section 3 states the identified research gap and shows the requirements to be met by the concept. Section 4 outlines the concept and section 5 its exemplary implementation. Section 6 lists the conducted tests and section 7 discusses the concept and its implementation.

2 RELATED WORK

This section illustrates an overview of high-level teleoperation concepts for road vehicles, the state of the art with respect to a related perception modification implementation, the common present AV architecture, and some of its challenges.

2.1 High-level Teleoperation Concepts for Road Vehicles

High-level teleoperation concepts are control concepts that transfer abstract control actions or signals to the vehicle, other than direct control signals. In other publications, they are called indirect control concepts (Gnatzig et al., 2013; Tikanmäki et al., 2017).

An example of a high-level teleoperation concept is the trajectory-control of Gnatzig et al. (2015, S. 53). The control signal is in the format of trajectories. Therefore, the control interface is on the level of guidance in accordance to Donges (1982). The teleoperator sets trajectories and supervises the vehicle's motion. Study results showed that the teleoperators steered the vehicle more stable than with direct control under a video streaming latency of 600 milliseconds. However, the teleoperators' workload was not measured. Furthermore, the trajectory control concept made only use of the vehicle's control algorithms, but not of its perception or planning capabilities. Therefore, it is suggested, that the teleoperator's workload might still be increased.

A similar teleoperation concept was patented by Biehler et al. (2017). Biehler suggests, that a teleoperator proposes actions in form of paths or trajectories. The trajectory is transmitted to the vehicle and the vehicle follows it under supervision or autonomously. However, it is questionable, why should the vehicle be able to proceed driving autonomously after the teleoperator's actions, when it could not do the task autonomously just a moment ago. Trajectory planners usually scan the complete free space for a drivable path. If no drivable path is found by the algorithm but a drivable path exists, the problem probably lies in perception, not planning. Therefore, the concept of teleoperator-provided actions and onboard responsibility is questionable.

A high-level teleoperation concept could be that the teleoperator confirms, modifies or rejects behavior suggestions of the vehicle. Similar ideas to safely control an AV remotely are patented. It is worth mentioning, teleoperator confirmations, modifications or rejections for the AV behavior suggestions (Fairfield et al., 2019; Lockwood et al., 2019), or the marking of non-passable corridors (Levinson et al., 2017). However, no references to implementations or evaluations could be found.

Therefore, ideas and concepts for high-level teleoperation concepts already exists. They have the potential to enable an AV to proceed and to keep the teleoperator's workload low. However, no implementation or evaluation of workload can be found. Nevertheless, it is assumed, that high-level teleoperation concepts have the potential to decrease teleoperators' workload due to simplification of control tasks. In order to be able to make statements regarding the feasibility and the workload of high-level teleoperation concepts, they have to be implemented, compared and evaluated.

2.2 Object Connotation Modification in Shared Autonomy

Pitzer et al. designed and tested a shared autonomy concept between a handling robot and a human operator (Pitzer et al., 2011). The robot's task is to pick and relocate selected objects. The human operator can support the robot's perception, if the robot cannot find a certain object. The operator selects the desired object on a monitor and the robot then uses this information to pick the specified object without further user help. Pitzer et al. pursued a similar concept as in this paper, where the robot's perception is assisted, the context and the implementation however differ significantly.

An Uber Technologies patent (Kroop et al., 2019) considers a similar idea as developed to the one in this paper. The patent states, that the self-driving vehicle identifies indeterminate objects, sends the encoded sensor data to a back-end and receives the required information in order to resolve the actual situation. However, no publication containing an implementation can be found. Furthermore, little information about technical challenges is elaborated. For example, perception is commonly represented in different ways. However, the handling of other representations than objects is not covered.

2.3 Software Architecture of Automated Vehicles

Perception modification requires an interface to the perception output. This interface has to be provided by the automation architecture. For example, the sense-plan-act architecture allows such an interface. The end-to-end architecture generally not. Common architectures are introduced to be aware of the correct context.

Currently, two approaches are widely used to define the software architecture for automated driving. First, end-to-end automation (Xu et al., 2016; Xiao et al., 2019; Bojarski et al., 2016; Pan et al., 2017; Zhang, 2019) and second, modular sense-plan-act architecture (Pendleton et al., 2017). Given the higher number of publications, modular sense-plan-act architecture is more common in research than end-to-end automation. Sense-plan-act architecture is divided into submodules and each of these is currently a research topic by itself. One of the challenging parts is the perception module. The goal of perception is to provide the contextual representation of the vehicle's surroundings. This is usually done by locating relevant objects and understanding their semantic meaning. It must also be mentioned, that there is already an ETSI norm on Collective Perception Service that standardizes perception messages for V2X-communication (ETSI TR 103 562, 2019).

2.4 Preventing False Negatives Leads to False Positives

False positives remain a challenge to perception, even if there are algorithms that reduce their occurrence. For example, Gies et al. (2018) track and fuse objects of different detection algorithms while considering constraints such as physical, module and digital map constraints in order to reduce false positives and uncertain states. Furthermore, Durand et al. (2019) introduced a confidence score using the number of sensors covering a detection, the detection's lifetime and the respective sensor failure history. Moreover, Kamann et al. (2018) developed a model to calculate radar wave propagation in order to remove reflections from the raw sensor output that would lead to false-positive detections. The mentioned algorithms as well as many others reduce the number of false positives (Jo et al., 2017; Bauer et al., 2019; Mita et al., 2019). However, some false positive detections persist (Jo et al., 2017; Bauer et al., 2019).

In general, one premise for AV is that relevant objects must not be overlooked. An overlooked object is called a false negative. However, preventing the occurrence of false negatives comes with the rise of the occurrence of false positives detections without corresponding real objects. At the moment, the dilemma in object detection is that the number of false negatives and false positives cannot be minimized simultaneously. The reason is that a confidence score threshold has to be set, that results in the following trade-off: the lower the threshold is, the fewer objects are overlooked. But this also means, that more false positives can occur. On the other hand, the higher the threshold is, the fewer false positives occur, but the higher the number of overlooked objects is. Since overlooked objects might lead to a crash, false negatives are unacceptable for an AV.

Therefore, false positive detections will occur in the future. False positive detections can hinder the AV from reaching its destination.

2.5 Indeterminate Objects

Indeterminate objects are detections that are insufficiently interpreted or incorrectly classified by the detection algorithm. Such objects might not be familiar to the detection algorithm when the AV is launched. Reasons for that could be missing labeled data during the training process of the detection algorithm or the vehicle operation in an unforeseen domain. Therefore, the detection algorithm interprets such detections inappropriately. Examples could be some kind of debris, lost cargo, packaging, branchlets or steaming gully covers. Furthermore, misinterpreted lane markings or road signs might be an issue. Some of those detections would not hinder a human's drive. Therefore, the AV could proceed.

3 OBJECTIVE AND REQUIREMENTS

The following research gap has been identified from the related work. It is not researched yet, if a teleoperator can correct the AV perception so that the AV can continue to drive. It is suggested that such a teleoperation concept places less workload on teleoperators than direct control. Therefore, the aim of this article is to present the feasibility and the implementation of a high-level teleoperation concept that enables the teleoperator to correct the AV perception. The high-level teleoperation concept should meet the following requirements.

First, it has to solve a specific scenario: The AV trajectory planner does not find a drivable path due to a mistaken obstructive detection. The mistaken obstructive detection can be a false positive or an indeterminate object as mentioned in sections 2.4 and 2.5.

The second requirement is that the teleoperator should only intervene minimally in the system. The underlying assumption is, that the workload is low if the teleoperator has to do little.

The third requirement is that its usage has to be safe. The teleoperator has to be able to distinguish between scenarios in which the concept can be applied and in which not. Moreover, the teleoperator has to comprehend the consequences of the perception correction. Finally, the teleoperator has to be able to withdraw the perception correction if something unexpected happens.

4 THE PROPOSED CONCEPT

In consideration of the mentioned requirements, a concept is proposed that enables the teleoperator to mark areas as drivable. Therefore, the AV is able to continue the drive.

4.1 Integration into an Automated Vehicle System Architecture

The goal of the presented method is to support the AV in situations where the vehicle's trajectory planner cannot find a feasible trajectory due to a mistaken obstructing detection. The automation architecture at hand is the sense-plan-act architecture as depicted at the bottom of Figure 1. The interface is placed between the output of the perception module and the input to the planning module. The module is called perception modification as visualized in Figure 1.

At the vehicle, data routing in the sense-plan-act architecture is changed. Under normal vehicle operation, the output of perception is the direct input for planning. In perception modification mode however, the perception modification vehicle module is placed between the perception and planning module. Consequently, the input to the planning module is the possibly modified output from the perception modification module. The perception is as commonly used represented by a dynamic occupancy grid map and an object list (Pendleton et al., 2017; Gies et al., 2018).

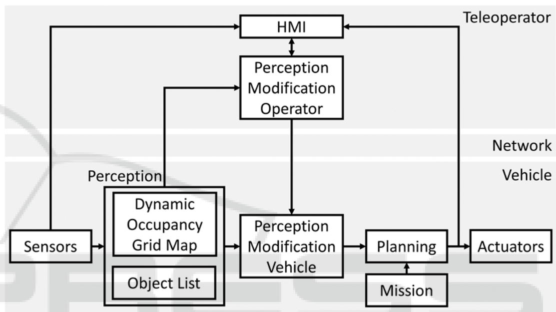

Figure 1: Architecture of the perception modification concept.

4.2 The Perception Modification Module

The teleoperator interacts with a human-machine-interface (HMI). The HMI has two essential functions: First, it provides the teleoperator with the required information about the current situation. Second, it accepts the teleoperator's input in regard to the drivable area. Figure 2 depicts these functions.

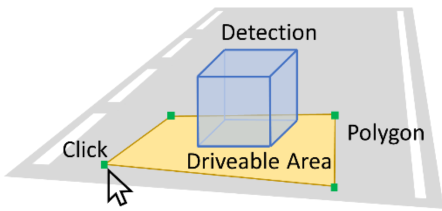

Figure 2: Schematic depiction of the teleoperator's HMI. Detections are illustrated as 3D objects with their actual dimensions. The driveable area can be marked.

The required information about the current situation is:

- Video streams
- Objects
- Dynamic occupancy grid map
- Mission or desired behavior
- Current trajectory

The perception modification module must have at least these functions:

- Take the drivable area as an input
- Recognize detections within that area
- Tag those detections as ‘ignored’

The teleoperator is responsible for supervision of the marked area. As soon as the marked area is not drivable anymore, the teleoperator has to withdraw the marked area. In order to have enough time to do so, the maximum speed of the AV should be restricted while driving based on the modified perception data.

The consequences of the perception modification have to be comprehended by the teleoperator. Therefore, two modes within the perception modification are proposed: Planning mode and Driving mode. In planning mode, the consequences of the perception correction are only visualized, but not performed. This includes the affected detections and the planned vehicle’s trajectory. During driving mode, the vehicle acts according to the modified perception.

4.3 Shared Responsibility

The teleoperator only has responsibility for the marked area. Therefore, the remaining area is not affected by the perception modification and will still be handled by the vehicle. Furthermore, the plan and act part of the sense-plan-act architecture is carried out by the vehicle completely independently. The teleoperator does not intervene in any modules other than the perception modification module.

The additional responsibility of the teleoperator is it to identify situations that are not resolvable with the perception modification concept. Examples are objects that must not be ignored or occlusions or blind spots that hinder the teleoperator’s view.

5 IMPLEMENTATION

The following section describes the experimental implementation of the perception modification concept in a simulation environment.

5.1 System Setup

The experimental setup aims to resemble an AV and its behavior in the situation where a false-positive is blocking the all possible trajectories of the vehicle. A simulator is utilized to provide sensor data, ego vehicle motion and the environment. The author used the LGSVL simulator for that purpose (Rong et al., 2020). The considered software modules were implemented in C++ and made use of the ROS Melodic framework. Both a grid map representation as well as an object list were implemented and presented to demonstrate the compatibility with the system architecture. The implemented setup based on the architecture depicted in Figure 1.

5.2 The Algorithms

The HMI module and the perception modification module are the central modules under consideration here.

Figure 3 depicts the HMI, that is mainly based on Georg and Diermeyer (2019). It visualizes the vehicle’s position on a 3D plane and projects the camera feeds onto a sphere which moves along with the vehicle.

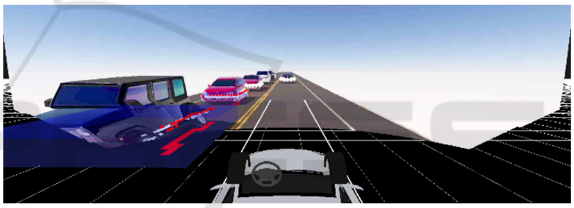

Figure 3: The teleoperator’s view in the HMI module. Detected objects (blue), lidar reflections (red points), the occupancy grid map (red rectangles) and the current trajectory (white lines) are visualized as 3D objects.

The HMI was extended. Whenever the teleoperator clicks within that visualization, the 3D position of the click is processed by the perception modification module. Keyboard presses are treated similarly. With these features, the teleoperator creates polygons on the floor. These polygons are interpreted by the perception modification module as the drivable area. With keyboard presses, the status of the perception modification module is changed from ‘planning’ to ‘driving’ and back. In planning mode, the teleoperator creates polygons and sees the potential effect of those changes to the vehicle behavior. The vehicle’s new planned path is visualized. However, the planned path is not conducted by the vehicle in ‘planning’ mode. First, the teleoperator has to confirm and switch into ‘driving’ mode. In driving mode, the vehicle drives along the planned path.

The grid map module at the vehicle side aims to resemble a dynamic occupancy grid map similar to published grid maps (Nuss et al., 2016). For the sake of simplicity, the grid map at hand is constructed based on the single-layer lidar information and makes use of the ANYbotics grid map library (Fankhauser und Hutter, 2016).

The detection module is also based on the reflections provided by the single-layer lidar sensor. The module provides 3D objects described with position, dimension and velocity.

The planning module as depicted in Figure 1 is kept comparably elementary. A module creates a straight path based on the current position with a fixed maximum velocity. A collision detection module reacts to occupied fields or hindering objects and reduces the absolute velocity of the velocity profile of the straight path. Therefore, the vehicle reacts to hindering objects with a standstill.

5.3 Simulating Non-existing Hindering Objects

The grid map module and the object detection module are extended to create synthetic false positives. This feature reproduces the situations described in subsection 3.3. In the case of a false positive detection in the object list, an object without a real physical representation in form of lidar reflections can be created. Figure 4 shows such a false positive detection in front of the ego vehicle. Similarly, synthetic false positives can be created in the grid map.

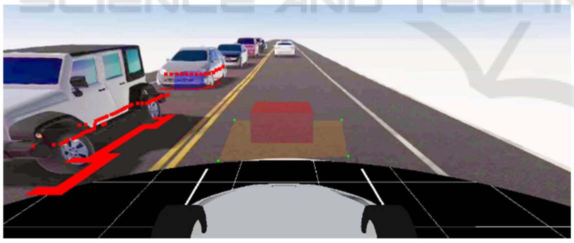

Figure 4: False positive detected object (red) in front of the ego vehicle enclosed by a clicked polygon (green points, orange area).

6 RESULTS

The following tests were conducted in order to show the feasibility of the perception modification concept and to draw conclusions for further improvements and open questions. The tests cases are:

- False positive in the object list and no wrong detection in the grid map.
- False positive in the grid map and no wrong detection in the object list.
- False positive in the grid map and in the object list.
- False positive in grid map 1m in front of a real object and no wrong detection in object list.
- Correct detection

Therefore, the test cases cover the range of applications of the perception modification concept. In the scenarios representing an unnecessary stand still, the perception modification concept enabled the teleoperator to modify the incorrect perception and the vehicle to continue driving. Situations regarding a correct standstill were recognized as such.

7 DISCUSSION

The conducted tests show the feasibility of the perception modification concept. However, further considerations are presented to enable implementation on the real vehicle.

Additional latency to the system setup arises due to the transmission of the object list and the grid map representation over the mobile network twice. This is not considered in the system setup yet. However, its influence can be estimated. Mean ping times are estimated to be around 45 to 59 milliseconds (Neumeier et al., 2019). The additional latency would be equal or higher than these values. Only the teleoperator has to compensate this latency during the supervision task. The vehicle-internal automation pipeline is not affected by that latency.

Finally, maps are not considered at the moment. They are usually part of an AV and can provide mistaken obstructing objects as well. In that case, the current interface could be extended to be capable of modifying map data.

8 CONCLUSIONS

A perception modification concept to free the path of an AV is developed and demonstrated in this paper. The results of the simulation test cases show that the teleoperation concept enables teleoperators to resolve the respective situations appropriately. The situation addressed is a mistaken hindering detection that causes a standstill of the AV. The detection is either a false positive or an indeterminate object which can be ignored. The teleoperator marks the drivable area and enables the AV to continue its drive.

It is expected that the teleoperators are therefore imposed with less workload compared to direct teleoperation concepts. This has to be shown in future studies.

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